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CHARGE CONTROL FOR SILVER CADMIUM AND SILVER ZINC CELLS

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Since 1961, several scientific satellites have been flown by the Goddard Space Flight Center using sealed, non-magnetic silver cadmium batteries for secondary power. These satellites have been designated as Explorer XII, XIV, XV, XXVI, and IMP's I, II, and III. The orbital periods of these satellites have been from a nominal five hours for Explorer XV to 100 hours for IMP III. In all cases, the thirteen cell batteries have been nominal five ampere hour cells which have been encapsulated in epoxy resin. The configuration of the batteries has changed but a typical construction is described in reference (1). Except for IMP III, the method of charging employed has been constant potential using 1.51 volts per cell as the voltage limit over the operating temperature of 0 to 40 degrees Centigrade. Current limiters have not been used. The current limiting characteristics of the solar array has served to prevent delivery of excess currents to the battery at the beginning of charge.

The Explorer Satellites, and in particular the IMP Satellites, are subjected to continuous sunlight for extended periods of time. Under this condition the battery can be fully charged and will be overcharged even though low current values are prevalent. As is well known, the use of continuous constant potential charging will result in an unbalance of the individual cell voltages allowing one

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or more cells to exceed the average charge voltage and rise above the gassing potential level causing excessive internal pressures. This is true especially if hydrogen is evolved. During the programs carried out at the Goddard Space Flight Center, it has been observed that cell unbalance begins when silver cadmium cells are constant potential charged and the charge current tapers and approaches $C/100$, where C is the rated cell capacity at the two hour rate at room temperature. When the charge current has leveled off to $C/1000$ or less, the unbalance condition becomes quite pronounced and cell voltages will vary from 1.4 to 1.8 volts per cell when, as previously mentioned, the average charge voltage is maintained at 1.51 volts per cell.

Several test programs have been conducted at Goddard to determine the effects of cell unbalance on battery performance. Typical data from these programs have been reported previously. (1), (2), and (3). It has been shown that it is possible to operate sealed silver cadmium cells in series even though the cell unbalance condition exists. However, during the course of the evaluation some cells (dependent on lot to lot variations) would exhibit excessive pressure during unbalance that has resulted in rupture of the epoxy seal. Since it was not possible to develop a technique to predict the mavericks, it became necessary to develop a method of charge control to eliminate the unbalance condition.

One method was developed by the Marine Engineering Station (Annapolis) on contract to Goddard wherein individual cell sensing could be used to monitor individual cells during charge. The results of this work are reported in

reference (4). However individual cell sensing of silver cadmium cells during charge is complicated by the fact that, during the transition of the silver electrode from Ag_2O to Ag_0 , a voltage peak occurs that can exceed 1.50 volts.⁽⁵⁾ It has been observed that this peak is dependent on charging rate and temperature.⁽⁶⁾ If a cell sensing circuit is incorporated into a power system to terminate charge when any cell would approach say 1.55 volts, the circuitry would have to differentiate between the transition peak and the unbalance condition. Although such a device may be feasible, it would become quite complicated. A method has been developed at Goddard that, from laboratory and flight experience, has essentially eliminated the cell unbalance problem. Resulting from the development, it appears that the solution to additional problem areas, that have been experienced in flight and test programs, are solvable by means of the developed technique. These problem areas are the pulse charge-discharge operation of batteries, prevalent on the Explorer and IMP series of satellites, and the oxidation of conductive free silver in the positive electrode that can result in a dip in battery voltage at initial discharge. Also, limited testing of the charge control method on a sealed, ten cell, silver oxide zinc battery has shown that the method is advantageous in preventing premature catastrophic failure of this electrochemical system during cycling.

Basically, the charge control method utilizes current sensing to determine a preset value of charge current as the current tapers during constant potential charging. This preset current value is chosen as an indication of nearly full

charge of the battery. As shown in figure (1), a current detector is in series with a multi-celled battery. A shunt regulator controls the charge voltage across the battery. The charge voltage can be reset from a high voltage during battery charging to a low voltage when the battery is near full charge. Voltage reset is controlled by the current preset value of the current sensor. This method has been entitled a two step voltage limiter. Laboratory equipment designed to accomplish this type of charge control is reported in reference (7).

In applications where silver oxide cadmium cells are used, the high voltage limit is set at 1.51 volts per cell whereas the low voltage limit is set at the open circuit voltage of 1.41 volts per cell. In practice, the current trip value to determine the shift to a lower voltage, has been set at $C/100$. The accuracy of this value is not critical and experience has shown that trip values between $C/50$ and $C/100$ are permissible. By maintaining a charge voltage of 1.41 volts per cell across the battery a cell voltage unbalance condition cannot exist when a satellite is subjected to periods of continuous sunlight or prolonged periods of trickle charge at low ($C/1000$) current values.

The operation is shown in figure (2) where the voltage-current characteristics of a cell in a battery are shown. The dotted lines show the normal voltage-current characteristics as the cell becomes charged and the charge current is essentially zero. At this low current value the cell may exhibit a charge voltage between 1.41 and 1.80 volts. Using the two step voltage limit method, when the current is at $C/100$ (point B), the battery voltage is decreased from 1.51 to 1.41

volts per cell (point A). Obviously, if a cell shorted internally, an unbalance condition could arise. Extensive testing on silver oxide cadmium cells has shown that shorting has not been a major problem at temperatures of 25°C or less.

One additional condition is imposed on the control system. The current sensors used in flight do not sense polarity. At any time the current through the sensor is greater than $C/100$, the voltage regulator is set at 1.51 volts per cell. Consequently, when the battery is discharged at currents greater than $C/100$, the shunt regulator shifts to the higher voltage. When the satellite enters the sunlight, the array will deliver the total current available for charge.

Use of the charge control method has shown that about 90% charging of the battery is accomplished at room temperature. On IMP satellite applications, normally 25% of rated capacity is used in shadow periods. On occasion, orbital conditions require that the battery be discharged to 0.9 volts per cell. In neither case is the decrease of total capacity detrimental to satellite operation.

The Explorer and IMP type spacecraft are spin stabilized satellites with four solar paddles arranged in a fan type configuration. A typical IMP Satellite is shown in figure (3). The output of the solar array varies due to the spin of the spacecraft. At various times over the lifetime of the spacecraft, this can result in pulsing of the battery in sunlight when the satellite spins and presents varying paddle areas to the impinging sunlight. At certain roll positions, the illuminated paddle area is insufficient to produce enough power to operate the

spacecraft. At this instant, the battery is called upon to supply the deficiency. A few degrees later in the revolution, the area will increase providing the necessary power for the spacecraft as well as power to recharge the battery. Consequently, alternate charging and discharging of the battery occurs.⁽⁸⁾ As a result of the charge discharge regime, two conditions can exist: undercharging or overcharging of the battery. Which conditions will exist depends on the ampere seconds removed from the battery during the discharge pulse and the amount of current available during the charge pulse. If the battery is discharged during this mode of operation, the payload is removed from the line when the battery voltage on load is 0.93 volts per cell. The total array power is available for battery recharge for at least four hours. However, laboratory tests have shown that, when the discharge pulse is of the order of 100 milliamperes or less, dependent on the amount of charge current available, the battery can be overcharged. The excess coulombs can result in an overcharge condition where gas is generated that cannot be recombined.

In figure (4), typical pulse charge-discharge cycling encountered on a satellite is shown. After the battery is discharged in the earth's shadow, as the satellite enters the sunlight the condition of pulsing occurs. On this spacecraft, the voltage limit on charge was 1.51 volts per cell. Laboratory experiments have shown that if the depth of the discharge current pulses was 100 milliamperes or less, the battery could be charged under these conditions. However, it was also noted the integral of the charge pulses (A) would exceed the integral of

the discharge pulses (B). If the battery was subjected to prolonged periods of sunlight under these conditions, it was possible that battery failure could result.

Realization that this condition could exist on the Explorer IMP Satellites also prompted development of the two step voltage limiter. Operation of the charge control method, during one pulse, is explained by figure (5). At time zero the current is essentially zero. Since the current sensor does not sense polarity, as the battery is pulse discharged, the charge voltage resets to 1.51 volts per cell at point A and then resets to 1.41 volts per cell at point B. During the charge pulse, if the battery is near full charge, the pulse height will be low, below the current trip setting. In other words, the battery has to accept current greater than the current trip value (I_{trip}) at 1.41 volts per cell. If the battery is discharged about 25% the height of the charge pulse will exceed the current trip setting thus signalling the voltage limit to reset to 1.51 volts per cell. Consequently, useful capacity can be supplied to the battery.

The charge control method has hopefully eliminated one additional problem. If silver cadmium cells are allowed to float for several months at a voltage of 1.51 volts, the minute flow of current through the cells will tend to oxidize most of the free silver in the positive electrode that is normally available for the conduction of current through the electrode. Analysis of electrodes has shown that floating at 1.51 volts can reduce the amount of silver by 50%. It is suspected that this reduction can result in a voltage dip, below 1.0 volts, on initial discharge after the long charge. The two step voltage limit method prevents

full charging of the cells. Tests at NAD/Crane have shown in cycle regimes, which include prolonged charging at 1.41 volts, the voltage dip has not been experienced.

Limited testing has been performed on sealed, secondary silver oxide-zinc batteries using the two step voltage limiting method. A control battery of ten cells was compared with a test battery of ten cells using the charge control device described in reference (7). All cells were individually sealed in epoxy. The cells were 12 AH nominal capacity while the rated capacity was 17.5 AH at the 5.0 ampere discharge rate at room temperature. In both cycling tests, the cells were discharged at 5.0 amperes for one hour and recharged in twenty-three hours. The control battery was constant potential charged at 1.98 ± 0.01 volts per cell while the voltage limit on the test battery was 1.98 ± 0.01 volts per cell but this voltage was reduced to 1.87 ± 0.01 when the charge current tapered to 200 ma. The current limit on charge was 500 ma. Typical charging curves for each battery are shown in figure (6).

The control battery failed on cycle 54 while the test battery failed on cycle 248. In each case, failure was the rupture of one cell. On cycle 42, the charge current of the control became irratic indicating cell shorting. During the last twenty cycles, the ampere hours into the battery exceeded the ampere hours out (5.0 AH) by about one ampere hour. This was due to the fact that one cell would remain at 1.57 volts during the entire charge cycle.

During the entire cycle life of the test unit, the ampere hour efficiency was close to 100%. At the lower voltage limit, some unbalance would occur. Beginning with cycle 83, the cell voltage unbalance of the lower limit was from 1.856 to 1.987 with one cell exhibiting the higher voltage. During the remaining cycles, one cell in the battery would charge at close to 2.0 volts while the remaining cells charged between 1.85 and 1.87 volts. The appearance of this high voltage cell did not follow any pattern, i.e., it would appear across different cells during the cycle test. However, it seems to be advantageous to use the two step voltage limit method on silver zinc cells. Maintenance of the lower voltage should lessen the problems encountered with zinc growths as experienced at the higher voltage (1.98) limit during the float portion of the charge. (9), (10).

The two step voltage limit type charge control, when used with silver cadmium cells, eliminates the unbalance problem, prevents overcharge during pulse charge-discharge cycling and appears to improve the discharge characteristics of the silver electrode. Use of the charge control method with silver zinc cells, in limited testing, increased cycle life by a factor of five. This type of charge control has been used successfully on the IMP III Satellite.

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CAPTIONS FOR FIGURES

Figure 1. Block Diagram - Typical Explorer Satellite Power System

Figure 2. Charge Characteristics - Ag-Cd Cell In Series

Figure 3. The IMP (Explorer XVIII) Satellite

Figure 4. Pulse Charge/Discharge of a AgCd Battery

Figure 5. Operation of the Two Step Voltage Limiter During One Pulse

Figure 6. Voltage-Current Characteristics on Charge Curve 1 - Control
Battery, Curve 2 - Test Battery